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Review Article

Examining the use of marble waste as a substitute of conventional materials in concrete: A brief review

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ABSTRACT

The use of waste marble in concrete as a substitute for conventional materials is gaining attention due to its potential environmental and economic benefits. This review comprehensively examines the feasibility of utilizing marble waste in concrete, focusing on three primary replacement levels: cement, fine aggregate, and coarse aggregate. The study synthesizes recent research on substituting marble waste for cement, fine aggregates, and coarse aggregates, focusing on performance metrics such as workability, strength, and durability. Findings reveal that waste marble can effectively replace up to 10% of cement in concrete mixtures. For fine aggregates, optimal replacement levels range between 20-30%, When used as a coarse aggregate substitute, marble waste can be replaced up to 50%, balancing improved resource efficiency with maintained strength and durability. The review highlights that incorporating waste marble into concrete not only reduces the reliance on natural resources but also minimizes landfill waste and lowers the carbon footprint. Recommendations for future research include standardizing marble waste particle sizes, evaluating long-term durability, and assessing environmental impacts through comprehensive life cycle analyses. This study aims to influence industry stakeholders and policymakers to consider waste marble as a viable and eco-friendly alternative in sustainable construction practices.

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INTRODUCTION

Concrete is among the most widely used construction materials across the globe because of its appropriate mechanical qualities, longevity, and ease of access. The world concrete consumption is estimated to about 25 billion tons per year [1]. Essentially, concrete is a composite material made up of four primary components: cement, fine aggregates, coarse aggregates, and water, the continuous utilization of this ingredients leads to the reduction of available natural materials. Approximately 70% of the concrete volume is composed of aggregates [2], These aggregates are obtained naturally from quarries and rivers [3]. The rise in concrete production leads to the depletion of natural resources and triggers environmental issues like soil erosion and habitat destruction. In order to eliminate this problem, numerous research initiatives have been undertaken to explore the substitution of aggregates with waste materials [4]. Numerous solid waste materials have the capacity to serve as substitutes for fine and coarse aggregates. These materials originate from agro-industrial processes and are often discarded in landfills, contributing to health and environmental concerns [5]. Marble

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dust is one of these waste materials.

Marble dust is a fine particle result from cutting process or polishing of marble. It does not possess pozzolanic properties, but it does produce more void-free concrete by filling in concrete mixtures [6]. It is usually produced in large amount during the mining and processing phases by Marble industry. This waste is dumped on open land, leading to various environmental hazards [7]. Also, these waste cause waterlogging, sterility to the land, and also causes harm to the ecosystem in the neighboring areas [8]. To curtail these environmental challenges, it is crucial to adopt sustainable approaches like proper waste management, recycling efforts, and the integration of eco-friendly technologies in the marble industry.

The sustainable utilization of marble waste in both concrete and sculptures is gaining attention as a means to moderate environmental concerns related to the construction industry. Marble waste, consisting mainly of marble fines and slurry, can be utilized effectively in various applications, thereby reducing waste disposal issues and promoting circular economy principles. In general, the distribution of marble waste generation by country is not readily available as a specific statistic. However, it is possible to approximate based on general knowledge of marble production, as waste generation is typically proportional to the amount of marble quarried and processed. The pie chart in Figure 1 illustrates the global distribution of marble waste generation, with a clear emphasis on the dominance of certain countries. Most notably, China emerges as the largest contributor to marble waste, emphasizing its significant role in the global marble industry. This substantial waste generation can be attributed to China's massive marble extraction and processing activities, which are driven by its extensive infrastructure development and construction projects [9]. Following China, other countries such as India, Turkey, and Italy also contribute considerably to global marble waste. These countries are well-known for their rich marble reserves and longstanding tradition in marble production. The distribution pattern observed in the pie chart highlights the geographical concentration of marble production and waste generation in specific regions. This distribution is influenced by factors such as the availability of marble reserves, the level of industrialization, and the demand for marble in domestic and international markets.

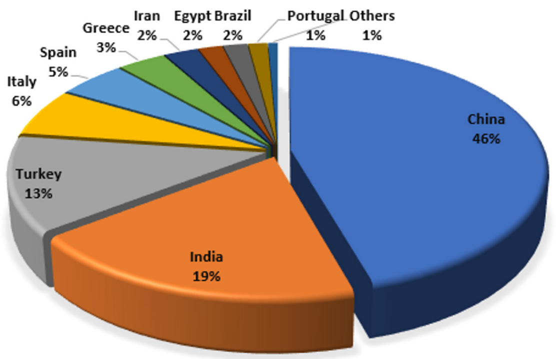

Figure 1. Global marble production by country (2023 estimates)[10]

In concrete production, marble waste serves as a partial replacement for natural aggregates like sand and gravel. This practice reduces the consumption of virgin raw materials, conserves natural resources, and lowers the overall cost of construction projects [11], [12], [13]. Studies indicate that incorporating marble waste into concrete can improve its mechanical and durability characteristics, such as enhanced compressive strength, split tensile strength, and resistance to acid attack [14].

Marble waste can also be employed in sculpture making, providing a unique and eco-friendly alternative to traditional carving materials. For instance, marble slurry can be molded into decorative elements, such as wall panels, floor tiles, and architectural details [13]. This approach allows for the repurposing of waste materials while offering innovative design solutions. Figure 2. (a) shows the dumped marble waste whereas figure 2 (b) displays the marble mining quarry.

Figure 2. (a) marble wastes (fine sized dust, middle and large sized marble pieces) [15]

Figure 2. (b) marble mining quarry [15]

SIGNIFICANCE OF THE REVIEW

This review primarily explores the potential of marble waste as a sustainable alternative in concrete production, addressing the dual challenges of waste management and resource depletion. By investigating the use of marble waste as a substitution for conventional materials such as cement, coarse aggregates, and fine aggregates, the review contributes to reducing the environmental impact of the construction industry. It critically assesses the technical feasibility and performance of marble waste in concrete applications, providing insights into its mechanical properties, durability, and overall effectiveness. Additionally, the review identifies challenges and research gaps, offering a roadmap for future studies by highlighting areas that require further investigation, such as long-term durability, environmental impact assessments, and the development of standardized guidelines. Ultimately, this study seeks to promote sustainable practices in the construction industry by demonstrating the positive environmental contributions and potential benefits of using marble waste in concrete, aiming to influence industry stakeholders, policymakers, and researchers to consider marble waste as a viable and eco-friendly alternative in the pursuit of sustainable development.

STUDIES INCLUDED IN THE SCOPE OF THE REVIEW

In this section, the utilization and recycling options for marble waste were thoroughly assessed through a comprehensive literature review, focusing on studies published after 2014. The review provides a detailed and concise summary of research conducted across various fields where waste marble dust has been applied.

Use of Marble Waste as a Partial Substitute for Traditional Coarse Aggregate

Numerous experimental studies have been conducted to assess the feasibility of using marble waste aggregate as a potential substitute for conventional natural coarse aggregate in concrete. The study conducted by [16], Marble waste aggregate was used in varying percentages from 0% to 100% by weight. The concrete mixtures were prepared with a constant water-cement ratio of 0.60. The result demonstrated a substantial improvement in the workability of concrete mixes that included marble aggregate of 11% more than that of control concrete. Similarly, all of the concrete mixtures with marble aggregate showed an average increase in compressive strength of 56% and 35% after 7 and 28 days, respectively.

In a similar study, Basaran et al. [17] examined the impact of substituting standard coarse aggregate with coarse marble aggregate in various proportions on the compressive strength of concrete. They analyzed a total of 93 compressive strength tests sourced from existing literature and conducted multivariate regression analyses on these results. Their findings revealed that replacing coarse aggregates with coarse marble aggregates can have both positive effects (increasing strength by up to 75%) and negative effects (decreasing strength by up to 32%) on concrete compressive strength. They also concluded that coarse marble aggregates can be used in substantial amounts, up to 50%, to achieve either a maximum increase or decrease in compressive strength.

However, Sowjanya et al. [18] studied the performance of concrete made with replacement of natural aggregate with black marble stone waste aggregates in proportion of (0%, 20%, 40%, 60%, 80%, and 100%). The results indicated a significant decline in workability and water absorption to about 42.85% and 91.46% respectively. Nevertheless, the compressive strength at 28-days curing age decreased to about 15.45% at 40% replacement level.

Saloni et al. [19] in their study discovers the using waste marble aggregates (WMA) as a substitute for natural aggregates (NA) in the production of sustainable alkali activated concrete (AAC). The research found that replacing up to 50% of NA with WMA led to an increase in the mechanical properties and elastic modulus of the AAC. However, the results indicates that higher replacement levels resulted in a non-homogeneous mixture and lower strength. Durability tests showed satisfactory gas permeation and resistivity up to 50% replacement, but water penetration resistance, density and slump decreased with the addition of WMA respectively. The study concludes that WMA can replace up to 50% of NA in AAC production, potentially leading to significant energy and cost savings and reducing environmental impacts from marble industries. Table 1 summarizes the experimental results of various tests conducted by different authors, comparing the use of marble-based aggregate with natural aggregate in the studies reviewed. Generally, the replacement of natural aggregates with marble waste led to notable improvements in the mechanical properties of concrete, as evidenced by the percentage increases in compressive, flexural, and splitting tensile strengths. These enhancements suggest that marble waste can contribute to a denser microstructure, which likely reduces the permeability of the concrete, as indicated by the reduced water penetration values. The variation in optimum replacement levels reported by different authors emphasizes the need for further research to determine the most effective replacement percentage, which may depend on factors such as the specific characteristics of the marble waste and the intended application of the concrete.

Use of Marble Waste as a Partial Substitute for Natural Sand

Marble Dust as a Fine Aggregate in Concrete Production

Marble dust has been extensively studied for its potential to replace fine aggregate in concrete mixes, specifically with water-cement ratios ranging from 0.4 to 0.6. The majority of investigations have employed marble dust with a calcite basis for their research [21]. Here, Demir [22] was conducting research in this field. Demir and Alyamac [22] used marble powder of different particle sizes to replace fine aggregate, in proportions of 0%, 8%, 16% and 24%. The results indicate that incorporating marble powder enhanced the compressive strength of the concrete mixes by 4.2% at an 8% substitution level, while workability diminished with incremental increases in marble powder replacement. The decrease in workability is associated with high water absorption characteristic by the marble powder which lead to a drier mixture as more water might be needed to achieve the desired consistency. Hence a high ranged water reducers admixture had to be used to improve the workability. Alyamac and Aydin [23] investigated the use of marble powder at 10%, 20%, 30%, 40%, 50%, and 90% by volume as a replacement for sand and examined compressive strength values at 7, 28, and 90 days. Their study found that marble powder is effective as a sand replacement material up to a 40% substitution level. Unconventionally, Ghani et al. [24] used waste marble powder (fineness modulus 0.99) as a partial replacement of sand (fineness modulus 3.00) they achieved a better performance in terms of compressive strength (an improvement up to 38.55% at 40%, and 28-days curing age) and splitting tensile strength at 20% replacement level. At 80% replacement level, these parameters were lower than those of the control concrete. The addition of waste marble dust to concrete in place of fine aggregate increases the material's tensile, flexural, and compressive strengths [25]. However, According to Memon et al. [5], Marble Powder (MP) may be able to partially substitute sand without sacrificing strength. Also, it was observed that the finest results were obtained when 50% of the sand was replaced with MP, which resulted in increases in compressive and flexural strength of 13.52% and 35.54%, respectively, above the control sample.

Varadharajan et al. [26] aimed to explores the substitution of cement with rice husk ash (RHA) and fine aggregate with marble waste powder (MWP) in concrete, along with the addition of 1.5% steel fibers. The study found that the optimal mix was 15% RHA, 30% MWP, and 1.5% steel fibers, which resulted in a 44.4%, 60%, and 46.13% increase in compressive strength, tensile strength, and flexural strength respectively. The combination also reduced porosity and water absorption. Despite a 6.3% cost increase, the improved mechanical properties and environmental benefits justified the cost. The environmental assessment showed significant reductions in CO2 emissions and particulate matter, contributing to a more sustainable and cleaner environment. The proposed equations from the regression analysis to determine the mechanical properties showed a high correlation with the experimental results.

Anitha et al. [27] investigated the use of marble Powder (MP) as a substitute for fine aggregates in concrete, aiming to reduce environmental degradation and material scarcity. The research involved replacing fine aggregate with MP in increments of 10%, up to 50%, in concrete specimens. These specimens were then cured for 7, 14, and 28 days. The results indicated that increasing marble powder (MP) ratios improved the mechanical properties of the concrete. However, the optimal mix was found to be with 10% MP, which demonstrated superior characteristics compared to control mixes. This suggests that MP can replace fine aggregate in concrete, enhancing efficiency and being cost-effective due to its availability and production. The study concludes that MP can replace up to 10% of fine aggregate in concrete, contributing to environmental and economic sustainability. The study also suggested that future work should investigate the durability characteristics of MP in concrete. The results summarized in the Table 2 provide a clear overview of the impact of using waste marble as a substitute for conventional fine aggregate in concrete mixes. Generally, the data reveals a consistent trend of enhanced mechanical properties, such as compressive, flexural, and splitting tensile strengths, across various replacement levels when compared to the control mix. The table also gave an insight on optimal replacement value at which the positive effects are maximized before a decline is observed.

Table 1. Results Summary: Marble Waste Replacing Conventional Coarse Aggregate in Concrete Mixes

References	Replacement Ratios	Slump (mm)	Compressive Strengthchange	Flexural Strength change	Split tensile strength change	Water penetration	Optimum replacement value
[16]	(0%, 20%, 40%, 60%, 80% and 100%)	Inc.	Inc. by 35% at 80% and 28-days curing age	-	-	Inc. by 83% at 80% replacement level	80%
[18]	(0%, 20%, 40%, 60%, 80% and 100%)	Inc.	Inc. by 15.45% at 40% and 28-days curing age	-	-	Dec. by 91.46% at 100% replacement level	40%
[20]	0-50% at 5% increment	-	Dec. by 4.49% at 30% and 28-days curing age	-	-	-	30%
[19]	(0%, 25%, 50%, 75% and 100%)	Dec.	Inc. by 25.11% at 50% and 28-days curing age	Inc. by 16.63% at 50% and 28-days curing age	Inc. by 11.92% at 50% and 28-days curing age	Dec. by 7% at 50% replacement level	50%

Table 2. Results Summary: Marble Waste Replacing Fine Aggregate in Concrete Mixes

References	Replacement Ratios	Slump (mm)	Compressive Strengthchange	Flexural Strength change	Split tensile strength change	Water absorption	Optimum replacement value
[22]	(0%, 8%, 16% and 24%)	Dec	Inc. by 4.2% at 8%	-	-	-	8%
[24]	(0%, 20%, 40% 60% and 80%)	Dec	Inc. by 38.55% at 40%	-	Inc. by 6.87% at 20%	Dec	40%
[25]	(0%, 25%, 50%, and 100%)	-	Inc. by 28% at 50%- and 28-days curing age	Inc. by 13.28% at 50%- and 28-days curing age	Dec. by 66% at 100% Replacement level	-	50%
[5]	(0%, 25%, 50%, 75%, and 100%)	-	Inc. by 13.52% at 50%- and 28-days curing age	Inc. by 35.54% at 50%- and 28-days curing age	-	-	50%
[28]	(0%, 5%, 10%, 15%, and 20%)	Inc	Inc. by 54.5% at 15%- and 28-days curing age	Inc. by 24.30% at 15%- and 28-days curing age	Inc. by 12.14% at 15%- and 28-days curing age	-	15%
[26]	(10%, 20% and 30%)	Dec	Inc. by 27% at 30%- and 28-days curing age	Inc. by 15.23% at 30%- and 28-days curing age	Inc. by 23.11% at 30%- and 28-days curing age	Reduced by 16.3% at 30%- and 28-days curing age	30%
[27]	(10%, 20%, 30%, 40%, and 50%)	Inc. by 14.28%	Inc. by 61.02% at 10%- and 28-days curing age	Inc. by 36.42% at 10%- and 28-days curing age	Inc. by 48.41% at 10%- and 28-days curing age	-	10%

Marble Dust as a Substitute of Fine Aggregate in Mortars

Kabeer and Vyas [29] evaluates the use of waste marble powder as a replacement for river sand in cement mortars. The research tested various mortar mix proportions and found that replacing 20% of river sand with marble powder enhances the workability, compressive strength, bond, and adhesive strengths of the mortar, while maintaining similar drying shrinkage, water absorption, and porosity to conventional mortars. This improvement is attributed to the thixotropic property of marble powder, which reduces water requirements and promotes the formation of a denser microstructure with superior hydration products. The findings suggest that incorporating marble powder in construction materials can significantly reduce the dependency on natural river sand and water, and provide a sustainable solution for marble waste management, contributing to a cleaner production process in the marble industry.

Bentlemsan et al. [30] explores the potential of recycling marble waste into self-compacting mortar (SCM) by substituting natural sand with various proportions of marble waste (MW). The findings indicate that substituting up to 50% of natural sand with MW enhances the workability and flow time of the mortar in its fresh state. Particularly at 30% substitution, both compressive and flexural strengths improved significantly at 90 days, with an 8% and 17% increase, respectively. Additionally, the porosity decreased by 27% at this substitution rate, indicating better durability. Marble-based mortars had enhanced strength after 180 days of immersion, demonstrating superior durability against sulfate attack. These results suggest that using marble waste as a substitute for natural sand not only enhances the mechanical properties and durability of SCM but also contributes to environmental sustainability by reducing quarry exploitation and waste disposal. Future research should investigate the leaching behavior, aging, and techno-economic feasibility of marble waste recycling.

Chahour and Safi [31] investigated the use of marble sand as a substitute for natural sand in mortar, examining its effects on properties like mechanical strength, rheology, and durability over curing periods up to 56 days. Mortars were prepared with varying marble sand content (0%, 30%, 50%, 70%, and 100%). Findings indicate that replacing natural sand with marble sand enhances compactness, compressive, flexural, and punching strength, particularly at a 50% substitution rate. Panels with 70% marble sand showed similar punching strength to control panels, and slabs with 100% marble sand displayed improved mechanical behavior. Durability tests revealed decreased weight loss due to acid attack with higher marble sand content, but water permeability increased beyond a 50% substitution rate. Overall, marble sand improves mechanical properties and conserves natural resources, although further research on durability is necessary.

Khyaliya et al. [32] used marble waste as a fine aggregate in lean mortar mixes, replacing river sand with marble waste in proportions ranging from 0% to 100% by volume. The best results were achieved with a 25% to 50% substitution, where water demand decreased by 6% and compressive strength significantly improved from 2.84 MPa to 7.04 MPa. The durability tests showed that mortars having 25% marble waste performed similarly to the control mix in aggressive environments. The study concluded that marble waste is suitable for both aggressive and non-aggressive environments, with 25% substitution recommended for aggressive conditions and up to 50% for non-aggressive conditions. Future research should include X-ray diffraction analysis to understand the mineralogical changes contributing to the improved performance of the mortar mixes.

Maza et al. [33] explores the recycling of marble waste in the form of powder and crushed aggregates as additions to cementitious building materials, aiming to enhance environmental protection. By incorporating marble powder into natural dune sand mortars and mixed sand mortars, the research achieved a notable decrease in porosity and significant improvements in mechanical properties. Specifically, a 15% marble powder addition, with or without admixture, improved compressive and flexural strengths. The use of crushed marble sand further optimized the granularity and cohesion of the mortar. Results showed that combining 15% marble powder with 20% crushed marble sand and a superplasticizer reduced water absorption and enhanced mechanical strengths, achieving compressive and flexural peaks of over 74 MPa and 12 MPa, respectively. The study concludes that recycling 35% of marble waste into the cement matrix effectively improves mortar properties and contributes to environmental conservation, recommending further research on substituting crushed marble with glass sand and marble powder with fine dune sand.

Marble Dust Used as a Fine Aggregate or Filler in Self-Compacting Concrete

Arun Kumar et al. [34] investigated the use of waste marble as a substitute for fine aggregate in self-compacting concrete (SCC), and polypropylene fiber as an additive to enhance flexural and tensile strength. Three replacement levels of 20%, 30%, and 40% were tested, with a fixed polypropylene fiber ratio of 0.4%. The results disclosed that up to 20% marble waste replacement improved compressive strength, while up to 40% replacement yielded acceptable fresh concrete results. The inclusion of fibers generally increased flexural and tensile strength. All fresh concrete properties were within acceptable values specified in European Federation of National Associations Representing producers and applicators of specialist building products for Concrete (EFNARC) guidelines, although the passing and filling capability reduced due to friction between powder particles and fiber surface area. Similarly, Vaidevi et al. [35] Investigates the application of marble waste as a fine aggregate in self-compacting concrete (SCC) for M60 grade, aiming to improve sustainability and workability. Various tests were conducted on fresh and hardened SCC, including slump flow, L-box, V-funnel, U-box, compressive strength, tensile strength, and flexure strength tests. The SCC specimens were cured for 14, 28, and 56 days with waste marble dust replacements of 0%, 25%, 50%, and 100%. Durability tests such as Rapid Chloride Penetration Test (RCPT), Water Penetration Test (WPT), and chemical attack tests were also conducted. The results showed that up to 25% replacement of fine aggregate with marble waste yielded satisfactory results in terms of workability, strength, and durability. Ahmadi et al. [36] aimed to investigates the potential of using waste from marble mining as a substitute for fine aggregates in the production of sustainable self-compacting concrete (SCC). According to the study, the compressive strength and flexural strength of the concrete were enhanced by adding 0.5% steel fiber by weight of cement and substituting up to 20% of the sand with marble waste. The presence of steel fibers was found to significantly improve the impact resistance of the specimens, more so than the recycled components. The study also revealed that fiber bridging greatly influences the final strength of specimens containing fibers. Furthermore, increasing the replacement percentage of recycled aggregates in the specimens enhances their resistance to impact loads. The water absorption rate showed no specific trend with the replacement of marble aggregates. Overall, the study concluded that SCC with recycled marble aggregate performed satisfactorily, demonstrating that the incorporation of recycled marble aggregate and steel fibers into self-compacting concrete can increase its mechanical properties and impact resistance.

Amit Kumar Tomar and Ankit Kumar [37] aimed to explores the properties of self-compacting concrete (SCC) when fine aggregate is replaced with waste marble powder at varying percentages (0%, 10%, 20%, 30%, 40%, and 50%). The research found that as the dose of waste marble powder increased, so did the workability of SCC. The most optimal results were observed at a 30% replacement level, where the fresh properties and compressive strength of the SCC outperformed other mixes at both 7 and 28 days. This suggests that waste marble powder could be a viable and effective substitute for fine aggregate in SCC, enhancing its performance and sustainability.

Karakurt and Dumangöz [38] investigated the use of waste marble dust (MD) and granulated blast furnace slag (GBFS) in the production of self-compacting concrete (SCC). The results revealed that the use of MD and GBFS improves the fresh and hardened properties of SCC. However, MD above a

10% ratio and GBFS above 30% negatively affect workability. GBFS contributes more to compressive strength compared to MD, with the maximum strength attained by the GBFS30 specimen due to its pozzolanic property. Both MD and GBFS improve the durability of SCC and contribute to pore filling. The use of these industrial wastes in SCC production not only increases concrete performance but also provides a solution for waste utilization. However, the transportation and screening of these wastes may raise the cost of SCC. Future research could investigate the compatibility of mineral additives and powder materials that enhance viscosity, as well as the use of binary and ternary combinations of MD and GBFS with other waste materials.

Singh et al. [39] studied the use of marble dust as a substitute for fine aggregates in concrete production. Experimental results showed that replacing up to 30% of sand with marble dust had slight effect on the compressive or flexural strength of the concrete. Specifically, the compressive strength increased by 4.9% with 15% marble dust, and by 12% with 30% marble dust. However, further increases in marble dust content (45% and 60%) resulted in smaller increases in compressive strength (3% and 2.1% respectively). Similar trends were observed for split tensile strength and flexural strength. The workability of the concrete was optimal at 30% marble dust replacement. However, workability and strength decreased as the concentration of marble dust increased beyond this point.

Use of Marble Dust as a Substitute for Cement in Concrete

Marble Dust as an Additional Cementitious Material for Concrete Production

The following research papers were identified that discuss the effects of marble dust as an additional cementitious material in concrete production.

Quanth and Kalra [40] carried out an experimental study on the use of marble dust powder as a partial replacement for cement and fine aggregates in concrete. In their research, natural fine aggregates were substituted with marble dust powder at replacement levels of 0%, 25%, 50%, and 100%, while cement was replaced by marble dust at 0%, 5%, and 10% replacement ratios. The results indicate that using marble powder up to 10% replacement by weight cement and 25% replacement by weight of fine aggregate can be effectively utilized without sacrificing concrete quality. Similarly, Gupta et al. [41] performed an experimental study on utilization of marble powder for sustainable construction, the results show that When marble dust powder containing less than or equal to 10% by replacement of cement slightly increases the compressive strength of the concrete and enhances the fresh properties of concrete such as workability and setting time. Raghunath et al. [42] conducted an experimental investigation into mechanical and durability properties of marble-powder-based high-strength concrete. It was observed that when cement is substituted with marble powder up to 10% the compressive strength, flexural strength and modulus of elasticity increases by 9.23%, 19.29% and 21.51% respectively. compared to the control specimen. Additionally, the test specimens showed minimal chloride ion penetration. However, both the marble powder concrete and conventional concrete displayed similar water absorption capacities. Rehan Ali [43] studied the influence of marble dust as a substitute of cement in concrete for environmental sustainability. The results indicated that replacing cement with marble dust at 5% and 10% has minimal impact on the strength of normal concrete at 7 and 28 days. Therefore, substituting up to 10% of cement with marble dust can be done without compromising the strength or workability of the concrete mix.

Yunusa et al. [44] Investigated the use of waste marble dust (WMD) as a partial replacement for cement in concrete. Concrete samples with 0%, 10%, 20%, and 30% WMD were tested for strength after 28 days of curing. The results showed that incorporating WMD significantly affected the compressive, split-tensile, and flexural strengths of the concrete, with the best performance at 20% replacement. This suggests that WMD can be effectively used in concrete production, helping to reduce environmental pollution, utilize waste profitably, and potentially lower construction costs since WMD is free. Therefore, a 20% replacement of cement with WMD is suggested for producing structural concrete. Chirumamilla et al. [45] in their study examines the use of marble powder as a cement substitute in M40 grade concrete to manage waste from the marble industry, which produces a large amount of dust. Cement was replaced with marble powder at 5%, 10%, 15%, 20%, and 25% by weight, and tests were carried out to measure compressive, split tensile, and flexural strength at 7, 28, 56, and 90 days. The findings revealed that replacing up to 20% of cement with marble powder enhances all three strength parameters, with the best results observed at 20% replacement. Beyond this point, strength started to decrease.

Kanhar et al. [46] examines the use of marble powder (MP) as a substitute for cement in M30 grade concrete to address environmental and waste management issues in Pakistan, where the marble industry contributes significantly to Gross Domestic Product (GDP) but also generates considerable waste. By substituting 5% and 10% of cement with MP, the research investigates the effects on workability, compressive strength, and flexural strength over time. Results showed that MP increases workability and, although initial compressive strength is lower, it improves significantly by 90 days, along with flexural strength. The summary of results in Table 3 emphasizes the considerable potential of using waste marble as a cement substitute in concrete mixes, demonstrating improvements in various mechanical and durability properties. The data shows that incorporating marble waste enhances compressive strength, flexural strength, and splitting tensile strength, frequently exceeding the performance of conventional mixes, especially at optimal replacement levels.

Table 3. Results Summary: Marble Waste Replacing Cement in Concrete Mixes

References	Replacement Ratios	Grade of concrete	Slump (mm)	Compressive Strengthchange	Flexural Strength change	Split tensile strength change	Water absorption (%)	Optimum replacement value
[41]	(0%, 5%, 10%, 20%, 30%, and 40%)		Dec	Inc. by 14.23% at 10%- and 28-days curing age	-	-	-	10%
[42]	(0%, 5%, 10%, 15%, and 20%)		-	Inc. by 19.23% at 10%- and 28-days curing age	Inc. by 19.29% at 10%- and 28-days curing age	-	Inc	10%
[43]	(0%, 5%, 10%, and 15%,)		Inc	Dec. by 16.7% at 15%- and 28-days curing age	-	-	-	10%
[44]	(0%, 10%, 20%, and 30%,)	M30	Inc	Inc. by 7.73% at 20%- and 28-days curing age	Inc. by 11.48% at 20%- and 28-days curing age	Inc. by 12.32% at 20%- and 28-days curing age	-	20%
[45]	(5%, 10%, 15%, 20% and 25%,)	M40	-	Inc. by 16.01% at 20%- and 28-days curing age	Inc. by 13.59% at 20%- and 28-days curing age	Inc. by 19.71% at 20%- and 28-days curing age	-	20%
[46]	(0%, 5%, and 10%,)	M30	Inc	Inc. by 17.27% at 10%- and 90-days curing age	Inc. by 12.54% at 5%- and 90-days curing age	-	-	10%

Table 4 presents a comprehensive summary of the physical characteristics of marble waste as reported by various authors, offering valuable insights into its potential as a substitute for conventional materials in concrete. The specific gravity which varies slightly across different studies, suggests that marble waste contributes to a denser concrete mix, which directly influences the weight and strength of the resulting concrete mix. Bulk density reflects the compactness of the waste, affecting the overall mass and porosity of the concrete. The maximum nominal size of the particles provides an indication of the aggregate's grading, which can impact the workability and compaction of the mix. Water absorption and fineness modulus are critical factors affecting the water-cement ratio and the fineness of the aggregate. Overall, these variations in physical characteristics highlight the importance of standardizing preparation and testing methods to ensure consistent and reliable results when incorporating marble waste into concrete.

Table 5 summarizes the oxide compositions of marble waste as reported by different authors, revealing a consistent trend across different studies. calcium oxide (CaO) emerges as the predominant component. The high CaO content emphasizes the potential of marble waste to act as a viable substitute for conventional cementitious materials. Calcium oxide is a primary ingredient in cement clinker, and its presence in marble waste suggests that this material could contribute to the strength and durability of concrete when used as a partial replacement for cement [48]. The reactivity of CaO in hydration reactions could enhance the overall performance of concrete, especially in terms of early strength development. However, the dominance of CaO in marble waste reflects its origin from calcite-rich marble, which is primarily composed of calcium carbonate ($CaCO_3$). During the processing of marble, $CaCO_3$ is converted into CaO, retaining its chemical identity. This consistent chemical profile across different sources of marble waste suggests a level of predictability in its behavior when used in concrete, which is advantageous for both researchers and practitioners.

Table 4. The physical characteristics of marble waste utilized by different authors

References	Marble wasteemployed as	Process for formation of aggregate	Specific Gravity	Water absorption (%)	Fineness Modulus	Maximum nominal size of Particle	Bulk Density (kg/m^3)	Specific surface area (cm^2/g)
[40]	cement and Fine aggregate	Crushing	2.60	0.80	2.03	-	1118	-
[22]	Fine aggregate	Crushing	2.71	-	-	2-4mm	-	3920
[24]	Fine aggregate	Crushing	2.41	0.34	0.99	0-1mm	8475	-
[47]	Cement	Marble dust obtained from	Inc	Inc. by 7.73% at 20%- and 28-days curing age	Inc. by 11.48% at 20%- and 28-days curing age	Inc. by 12.32% at 20%- and 28-days curing age	-	20%
[25]	Fine aggregate	Marble dust obtained from	-	2.50	< 300 microns	-	-	20%
[42]	Cement	Collected from local market	2.40	-	-	< 300 microns	-	-
[16]	Coarse aggre-gate	crushing	2.70	0.5	-	20mm	-	-
[18]	Coarse aggre-gate	crushing	2.77	0.6	3.49	20mm	-	-
[20]	Coarse aggre-gate	Broken marble tiles	2.10	0.1	-	20mm	-	-
[19]	Coarse aggre-gate	crushing	2.64	1.3	5.21	10-20mm	1383	-
[39]	Fine aggregate	crushing	3.02	-	3.79	-	690	-
[26]	Fine aggregate	crushing	2.64	1.83	2.45	-	-	-
[27]	Fine aggregate	crushing	2.445	-	8		2800	-
[29]	Fine aggregate in mortars	powder	2.70	-	-		1380	3500
[30]	Fine aggregate in mortars	crushing	2.556	0.5	2.7	Sieved through 5mm sieve	-	-
[31]	Fine aggregate in mortars	crushing	2.73	0.39	2.2	-	-	-
[32]	Fine aggregate in mortars	crushing	2.56	8.23	1.45	-	1670	-
[33]	Fine aggregate in mortars	crushing	2.63	-	2.98	Sieved through 5mm sieve	1780	-

Table 5. Oxides composition of marble waste utilized by different authors

References	SiO_2 (%)	CaO (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	Na_2O (%)	K_2O (%)	SO_3(%)	Loss of Ignition (%)
[22]	28.35	40.45	0.17	9.70	16.25	0.05	0.01	0.02	4.84
[24]	-	55.45	-	0.678	-	-	-	-	43.58
[47]	3.86	28.63	4.62	0.78	16.9	-	-	-	43.3
[41]	26.35	42.45	0.52	9.40	1.52	-	-	-	19.76
[16]	3.75	33.12	-	0.13	17.91	-	-	-	45.07
[42]	1.28	50.10	1.38	0.54	1.72	0.29	-	0.21	44.48
[19]	3.70	35.12	Traces	0.12	18.12	-	-	-	42.94
[36]	0.46	53.49	0.05	0.32	0.12	0.01	-	0.015	43.26
[38]	0.61	53.35	0.23	0.13	0.79	0.69	0.03	0.54	43.07
[26]	5.87	41.54	0.56	0.8	15.55	0.07	0.073	0.11	-
[27]	28.35	40.45	0.42	9.70	16.25	-	-	-	-
[29]	1.57	32.19	0.18	1.18	19.85	-	-	-	-
[30]	0.15	63.75	0.058	0.029	-	-	-	0.012	-
[31]	0.15	54.86	0.08	0.04	1.03	-	-	-	-
[32]	3.75	33.12	traces	0.13	17.91	-	-	-	45.07
[33]	-	55.78	0.09	0.01	0.47	-	-	0.05	-

COMPARISION AND DISCUSSION OF RESEARCH FINDINGS

In this section the comparative analysis and discussion were made for all the recycling options when waste marble based is used as a substitute for conventional materials in concrete.

Comparative Analysis of Waste Marble Dust as a Cement Substitute

Figure 4. (a) vividly illustrates the relationship between slump values and water-cement ratios when waste marble dust replaces cement in concrete. Remarkably, studies [22], [49] found that high slump values were achieved even with a low water-cement ratio. This suggests that marble dust may enhance workability due to its particle size and smooth texture, which could act as a lubricant within the mix. In contrast, studies [43] [46] [44] reported moderate slump values at higher water-cement ratios, indicating that increased water content was necessary to achieve workability. This likely stems from the marble dust's finer particles, which increase water demand due to a larger surface area for hydration. These findings highlight the variability in how marble dust affects concrete properties. While low water-cement ratios usually reduce workability, marble dust can mitigate this effect under certain conditions. Conversely, higher water-cement ratios needed for moderate slump values suggest that more water is required for mixes with higher replacement levels or different aggregate combinations. Overall, the results underscore the need for careful mix design adjustments to optimize performance when using waste marble dust as a cement substitute

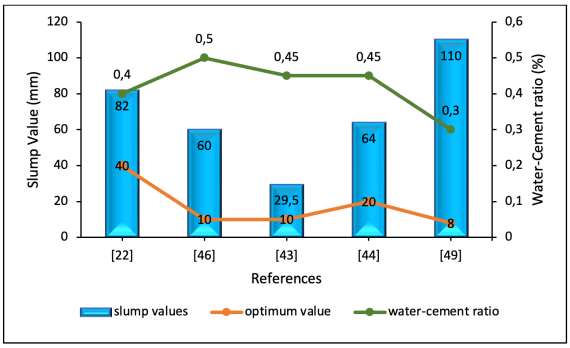

Figure 4. (a) Comparison of Slump, Water-cement Ratio, and Optimum Replacement level for cement substituted with waste marble dust

Comparative Analysis of Waste Marble Dust as a Fine Aggregate Substitute

Figure 4. (b) presents a comparison of slump values, water-cement ratios, and optimum replacement levels when substituting fine aggregate with waste marble dust. Studies [23],[24],[25] observed that higher replacement levels of marble dust led to lower slump values. This can be attributed to the dust's fine particle size, which increases the surface area and thus the water demand, resulting in reduced workability. As the replacement level rises, the mixture becomes denser and more cohesive, leading to lower slump values despite variations in the water-cement ratio. In contrast, studies [6],[27],[28] reported very high slump values at lower replacement levels, irrespective of the water-cement ratio. This indicates that when marble dust is used in smaller quantities, its impact on workability is less significant. The enhanced

fluidity at low replacement levels is likely due to the dust's ability to fill voids between aggregate particles, thereby improving workability without substantially increasing the water demand. Overall, these findings highlight that while waste marble dust can serve effectively as a fine aggregate replacement, its impact on slump values is highly dependent on the replacement level. Higher replacement levels generally reduce workability, necessitating adjustments in the mix design to achieve the desired balance between cohesion and flow properties. Conversely, at lower replacement levels, marble dust contributes positively to workability, offering potential benefits for improving concrete fluidity in specific applications.

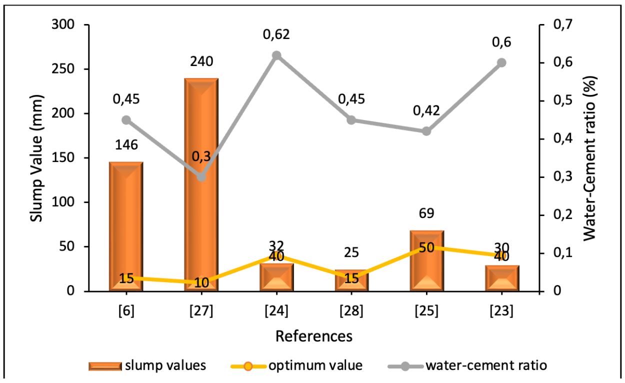

Figure 4. (b) Comparison of Slump, Water-cement Ratio, and Optimum Replacement level for fine aggregate substituted with waste marble dust

Comparative Analysis of Waste Marble Aggregate as Natural Coarse Aggregate Substitute

Figure 4. (c) compares slump, water-cement ratio, and optimum replacement level when substituting coarse aggregate with waste marble aggregate. The data shows that all reviewed studies report consistently high slump values at elevated replacement levels, regardless of the water-cement ratio. This consistent trend suggests that substituting marble aggregate for coarse aggregate significantly enhances workability. The high slump values observed can be attributed to the smooth texture and angular shape of marble aggregates, which reduce internal friction within the mix and facilitate better flow. Notably, the high slump remains stable across varying water-cement ratios, indicating that at high replacement levels, the characteristics of the marble aggregate dominate over traditional factors influencing workability. This is particularly advantageous in applications requiring high workability, such as complex formwork or densely reinforced sections. However, while the increased slump is beneficial, it is crucial to consider potential impacts on strength, durability, and overall mix stability. Excessive slump can sometimes lead to issues such as segregation or reduced structural integrity.

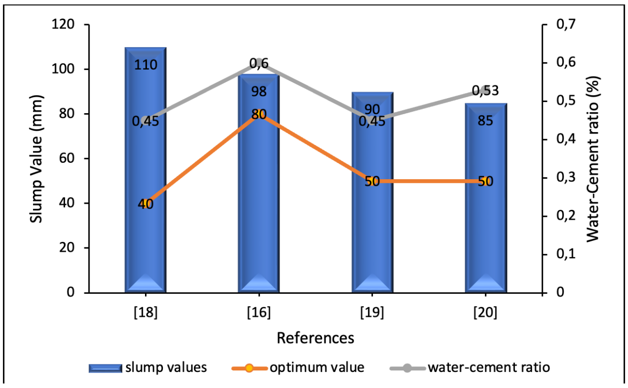

Figure 4. (c) Comparison of Slump, Water-cement Ratio, and Optimum Replacement level for coarse aggregate substituted with waste marble dust

CHALLENGES FOR FEATURE RESEARCH

Utilizing marble waste as a substitute for traditional materials in concrete presents both opportunities and challenges that require further research to optimize its application. One of the primary challenges is the heterogeneity of marble waste, which leads to variability in its properties and, consequently, the performance of the concrete. This variability makes it difficult to predict how marble waste will behave in concrete mixtures, necessitating more systematic studies to better understand its effects [50].

Another significant issue is the particle size distribution of marble waste, which can greatly influence the workability and strength of the concrete. Improperly sized particles can lead to problems such as poor workability and reduced strength, highlighting the need for standardized methods to achieve optimal particle sizes [51]. The chemical interactions between marble waste and cementitious materials also pose a challenge. Marble waste, particularly its calcium carbonate content, can influence the hydration process of cement, affecting the early strength and overall performance of the concrete. More detailed studies are needed to understand these interactions and optimize mix designs [52]. Optimizing these mix designs to balance strength, durability, and workability is another critical area of research. Finding the right proportion of marble waste as a substitute for conventional materials is complex and requires advanced modeling and experimentation [53].

Moreover, the lack of universally accepted standards and guidelines for the use of marble waste in concrete is a barrier to widespread adoption. Developing these standards, supported by robust research data, is essential for broader industry acceptance [52]. Finally, scaling up from laboratory research to real-world applications presents its own set of challenges. Transitioning to large-scale use requires adjustments in mix design, consistency in material properties, and thorough testing under varied conditions. Large-scale pilot projects and field studies are necessary to validate laboratory findings and ensure successful implementation [54].

ENVIRONMENTAL BENEFITS AND POSITIVE IMPACTS OF USING MARBLE WASTE IN CONCRETE

It has been testified from the previous researches that the use of marble waste especially in the production concrete offers numerous benefits ranging from environmental sustainability, economic efficiency, health and safety, innovation and research as well as performance related benefits.

By incorporating marble waste into concrete mixtures, their negative impact on environments is decreased. An example of this is the successful use of marble slurry in concrete pavements in Rajasthan, India, which not only utilized waste material but also led to improved pavement performance [55].

Integrating marble waste into concrete production can significantly boost job creation in both the recycling and manufacturing sectors [56]. This process involves collecting, processing, and repurposing marble waste, which requires a dedicated workforce for waste management, material handling, and quality control. For example, a company specializing in sustainable construction materials could establish a facility that employs local workers to crush and prepare marble waste for use in concrete mixtures. This not only diverts waste from landfills but also creates new employment opportunities across various stages of the supply chain, from waste collection to the final production of eco-friendly concrete products.

By incorporating marble waste into concrete production, companies not only reduce disposal costs but also create a market for eco-friendly building materials. For instance, marble dust can substitute part of the cement in concrete mixtures, enhancing the material's strength and durability. This innovative approach not only diminishes the environmental footprint of marble mining by repurposing waste but also addresses the construction industry's demand for sustainable materials. This symbiotic relationship between waste management and construction opens up new avenues for revenue while promoting environmental stewardship.

Utilizing marble waste in concrete production presents a significant environmental and health benefit by mitigating the rampant uncontrolled disposal of marble dust and fragments along roadsides, marble quarries, and in nearby environments (in some countries). This practice not only alleviates the unpleasant accumulation of waste but also importantly reduces air pollution associated with airborne marble dust particles. Such particles, when inhaled, can penetrate deep into the lungs, potentially leading to respiratory diseases. For instance, a study conducted in areas with high marble waste showed a marked decrease in local air quality, correlating with increased incidences of lung-related health issues among residents [26]. By incorporating marble waste into concrete, the generation of harmful dust is minimized, fostering a cleaner environment and promoting public health. Additionally, this practice exemplifies sustainable waste management and contributes to the circular economy by transforming a pollutant into a valuable construction resource.

Using marble waste in concrete production can significantly lower the overall carbon footprint of industries by reducing the need for energy-intensive quarrying and processing of new marble. Instead of discarding marble waste, it can be repurposed as a substitute for traditional concrete components. For instance, in the construction industry, incorporating marble waste into concrete mixtures can decrease the demand for freshly mined aggregates, which are typically extracted through environmentally damaging methods. This practice not only conserves natural resources but also cuts down on the emissions associated with mining and transporting new materials.

GAP IN RESEARCH

The majority of studies conducted in the recent literature focused on concrete grades of low to medium strength, ranging from M20 to M35. very rare studies were carried out on higher-grade concrete such as high strength concrete and high-performance concrete incorporating waste marble dust. However, with the limited data available from the research being conducted so far, concrete incorporating marble waste was found to be effective for the use in the construction of residential building and other structures that does not support heavy or dynamic loads. To enhance the application and utilization of marble waste in specific concrete types capable of supporting heavy and dynamic loads, such as in industrial buildings or railway sleepers, it is essential to conduct a comprehensive strength and durability analysis of high-grade concrete incorporating marble waste as a substitute for conventional materials. This would determine whether marble dust is suitable for use in high-strength concrete applications.

The compatibility of marble waste with various admixtures and additives in concrete is a critical yet often overlooked research gap in the field of sustainable construction materials. Marble waste, increasingly used as a partial replacement for conventional aggregates in concrete, interacts differently with chemical admixtures and additives such as superplasticizers, accelerators, retarders, and mineral admixtures like fly ash and silica fume. These interactions can significantly influence concrete properties including workability, early and long-term strength development, and durability. Understanding the specific effects of these additives on concrete containing marble waste is crucial for optimizing mixture proportions and achieving desired performance characteristics. Research addressing this gap would contribute significantly to advancing the sustainable use of marble waste in concrete, ensuring that its incorporation not only utilizes waste effectively but also enhances concrete performance in real-world applications.

The utilization of marble waste in concrete presents a promising avenue for sustainable construction practices. However, a significant research gap exists concerning the regional variations in marble waste characteristics and their direct impact on concrete properties. Most current studies are conducted in specific regions with access to particular types of marble waste, leading to findings that may not generalize across different geographical areas. Factors such as marble waste composition, waste particles' size distribution, and chemical properties can vary widely depending on the source location, affecting concrete's mechanical, durability, and aesthetic properties differently. Addressing these regional variations is crucial for developing concrete formulations that optimize the use of locally available marble waste while ensuring consistent and predictable performance across diverse environmental conditions and construction practices. Future research should focus on systematically exploring these variations to establish robust guidelines and standards for the effective integration of marble waste in concrete on a global scale.

The lack of standardized guidelines for incorporating marble waste in concrete presents a critical research gap that hinders its widespread adoption in construction practices. Currently, there is a notable absence of universally accepted procedures, comprehensive testing methods, and clear guidelines tailored for engineers and construction practitioners interested in utilizing marble waste as a supplementary material in concrete. This gap leads to inconsistencies in material properties, performance variations, and uncertainties regarding the long-term durability and structural integrity of concrete containing marble waste. Addressing this gap requires focused research efforts aimed at developing standardized protocols for the selection, processing, and incorporation of marble waste, as well as robust testing methodologies to ensure the reliability and predictability of concrete properties when incorporating these waste materials. Such guidelines are essential to foster confidence among stakeholders and encourage the broader adoption of sustainable construction practices leveraging marble waste.

Research in the field of utilizing marble waste in concrete predominantly centers on its compatibility with Portland cement, with significant strides made in understanding its effects on mechanical and durability properties. However, there remains a notable gap in investigating its compatibility with other types of cement, such as blended cements and sulfate-resistant cements. Blended cements, for instance, incorporate supplementary cementitious materials that could interact differently with marble waste compared to Portland cement, potentially altering concrete properties. Similarly, sulfate-resistant cements are designed for environments with high sulfate concentrations, presenting a distinct chemical environment that may affect the reactivity and performance of marble waste as a cementitious additive. Understanding these interactions is crucial for expanding the applicability of marble waste in various concrete applications, ensuring both sustainability and enhanced performance across different environmental conditions. Further research addressing these gaps could provide valuable insights into optimizing the use of marble waste in concrete beyond conventional Portland cement applications.

CONCLUSIONS

Based on the various studies accessed within the scope of the review the following conclusions can be drawn:

1.The use of waste marble in concrete production offers a dual benefit: it reduces costs while enhancing durability and addresses environmental challenges. Recycling waste marble not only supports the marble industry but also contributes significantly to the national economy. Efforts should be directed towards advancing recycling applications to maximize these benefits. This approach aligns with promoting environmental sustainability and safeguarding human health. Moreover, the findings from reviewed studies consistently highlight the potential of waste marble to improve concrete performance, making it a promising material for future sustainable construction practices.

2.The impact of incorporating waste marble in concrete on its strength has been extensively studied, revealing that substituting conventional materials with waste marble whether as coarse or fine aggregate, cement can increase the overall strength of the concrete. The strength gains are primarily attributed to better particle packing, reduced void content, and the pozzolanic reactivity of marble waste when used as a partial replacement for production of sustainable concrete.

3.The findings revealed that the optimal replacement level for waste marble powder as a cement substitute in concrete was 10%. At this replacement rate, the concrete exhibited its highest strength performance, indicating that incorporating 10% waste marble powder as a cement replacement produces the most favorable concrete strength.

4.The results demonstrated that substituting aggregate with waste marble in concrete proved to be more effective compared to using waste marble as a cement replacement.

5.The efficiency of replacing ordinary Portland cement (OPC) with marble waste can be improved when combined with other industrial by-products like ground granulated blast furnace slag (GGBS), silica fume, rice husk ash, and fly ash. The combined use results in a significant performance improvement that cannot be achieved when marble waste and these other materials are used individually.

6.The addition of marble powder generally requires water reducers like superplasticizers to maintain workability due to its high-water absorption. Moreover, innovative combinations, such as the incorporation of rice husk ash and steel fibers, have shown remarkable improvements in mechanical characteristics and environmental benefits, despite a slight cost increase.

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DATA AVAILABILITY STATEMENT

No data was used for the research described in the article.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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